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A technique for studying the local atmospheric diffusion of airborne material

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(Meteorological Office)

AIR MINISTRY
METEOROLOGICAL RESEARCH COMMITTEE

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Summary

A description is given of a technique for studying the atmospheric diffusion of particulate matter. Spores of Lycopodium released from a simple mechanical dispenser are collected on adhesive cylinders and subsequently counted under a microscope. The apparatus can be operated on captive balloon cables and used to investigate vertical diffusion at heights remote from the ground. The results of some preliminary experiments are discussed. The aim is to use diffusion measurements made by this technique in studying the relation between Lagrangian and Eulerian correlation coefficients in atmospheric flow.

Introduction

Much of the available knowledge of the processes of atmospheric diffusion has resulted from actual observations on the subsequent distribution in space of properties introduced naturally or deliberately into the air. In the particular case of airborne material these observations involve the collection and estimation of samples and, in experimental applications, the provision of a suitable source. These features present technical problems which increase in complexity as the region of the atmosphere to be studied becomes more remote from the laboratory and the ground, and as the number of samples required increases. The inevitable result has been that most data have so far been derived from relatively complex and cumbersome ground based arrangements for emission and sampling. Many ingenious techniques have been developed with one particular feature or another in mind, as for example in the ciné-photography of the horizontal spreading of a stream of bubbles released from a balloon-borne generator (Edinger, 1952), the use of fluorescent tracer material (Perkins et al, 1952) or the measurement of the local β-activity in a radioactive plume from a chimney (Stewart et al, 1954). However, if interest turns to a study of such diffusion processes without recourse to elaborate apparatus for sampling and estimation and without restriction to ground level operation there appears to be no well established technique.

In planning the observational aspects of a projected study of vertical diffusion in the first thousand feet or so of the atmosphere a promising basis for relatively simple measurements seemed to be provided by the impaction of airborne particles on cylindrical objects exposed to the airstream. A demonstration by this method of the turbulent diffusion in a wind tunnel airstream has already been provided by Gregory (1951) in his study of deposition of spores on cylinders and the method has also been used by Chamberlain (1953) in measuring airborne concentrations in some preliminary experiments on the deposition of particles on a natural surface. In the present case the interest lies in the

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application of this principle of impaction on cylinders to the examination of the vertical distribution shown by airborne particles after travelling some distance from a quasi-continuous point source operated at a considerable height above ground. The present note describes the equipment and technique as they have been developed so far and some of the experiences and results of preliminary experiments.

Equipment and Technique

Spores of Lycopodium appeared to be suitable particles for the present experiments. Their large size (30 μ diameter) facilitates examination of samples and their terminal velocity (1 - 2 cm./sec.) seems low enough not to affect their scattering in a turbulent atmosphere. The dispenser for producing the quasi-continuous emission consists of a hopper from which the spores are gravity fed on to a toothed wheel accommodated in a close fitting cavity in a perspex block. In the original version, the spores fell into a tube and were then blown out into the atmosphere by a current of air produced by a small air pump. In the latest version, shown in Figure 1, the spores fall from the toothed wheel through a vertical channel in the perspex block on to the blades of a small high speed fan operating in the free air immediately beneath the block. It had been previously demonstrated that the fan was effective in reducing the occurrence of aggregates of spores. The spores are emitted in discrete puffs but the speed of rotation of the wheel and the number of teeth are such that the interval between puffs is only 0.26 sec. From laboratory tests, the average rate of output is about 3 g./min.

The cylindrical surfaces used for sampling are simply 2" lengths of 0.25" external diameter glass tubing coated on the outside with a film of glycerine jelly similar to that described by Gregory (1951). Tubes of this size are convenient for handling and examination and their collection efficiency *, according to Gregory, exceeds 40 per cent in winds of more than 3.3 m./sec. In the present work, the tubes are exposed vertically on light metal vanes riding on small stops clamped to the cable of a Mark VI balloon, the vanes serving to keep the tubes upwind of the cable. The latest type of vane is shown in position on the cable in Figure 2. In practice a number of tubes is exposed at predetermined height intervals in order to explore the vertical distribution in a cloud of particles.

The general technique in the field operations is to position the Mark VI balloon at a suitable distance downwind of the dispenser, which can be set up either on the top of a tower or, for greater heights of operation, on the cable of another captive balloon. The dispenser is shown in Figure 3 mounted on the cable of a Mark X barrage balloon. Various aids to the positioning of the "sampling balloon" have been tried, such as a smoke candle or a small no-lift balloon tethered to a point near the dispenser. The latest method is to move the balloon into line with a pennant which is flown from the "source balloon" cable near the dispenser and which is observed in a horizontal mirror set up on the ground immediately below.

To estimate the deposit on the outer surface of a sampling tube, the tube is mounted on a horizontal spool attached to the stage of a microscope, the eyepiece of which is masked to give a field of view 0.11 cm. square. A section of tube 0.11 cm. long is then scanned by rotating the tube through 360

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* The collection efficiency is the number of particles impacting on the cylinder, expressed as a percentage of the number which would have passed through the same cross-sectional area if the cylinder had not been there. For a given particle size the collection efficiency depends on the type of adhesive used, the diameter of the cylinder and the speed of the air stream.

degrees and the number of spores which move across the field of view counted. This process is normally carried out at twenty points spaced 0.2 cm. apart along the tube and the mean number of spores taken as a measure of the deposit on the tube. If the efficiency of collection is the same for all tubes exposed in an experiment, the deposit can then be taken to be proportional to the concentration of spores in the air. The only systematic variation in efficiency which is known to occur is that due to the variation of wind speed with height above ground. As the experiments envisaged here involve sampling tubes spread out over a height range less than the height of the central tube, the variation in mean wind speed over the sampling positions will normally be within 15 per cent. For wind speeds of about 3 m./sec. the collection efficiencies (see Gregory (1951)) will vary only from 41 to 44 per cent. At higher wind speeds the variation will be less.

Lycopodium spores come from a type of moss which is usually found in mountainous districts. The spores are thus not commonly present in the atmosphere over Salisbury Plain, a fact confirmed by examination of tubes exposed while no emission was actually taking place. Their characteristic size, shape and yellow colour enable them to be distinguished from other particles collected on the sampling tubes. In the earlier stages of the work, however, positive identification was not always possible, for some particles were observed which were almost transparent but were similar in size and shape to Lycopodium spores. On investigation, these did in fact prove to be spores which were completely immersed in the jelly. With the incident light largely reflected at the surface of the jelly, they were subject to rather less illumination than those projecting from the jelly and showed up much fainter. This difficulty was overcome by using a more viscous jelly, obtained by doubling the proportion of gelatine recommended by Gregory. Tests showed that the majority of spores were then retained on the surface of the jelly and could be readily identified. As there was no apparent loss in efficiency, this form of jelly was adopted for all subsequent work. A further slight difference from the jelly used by Gregory is the inclusion of thymol instead of phenol.

Results of some preliminary experiments

The first few experiments were carried out with the dispenser operating for 15 minutes at a time on a tower 32.5 m. above the ground and the sampling tubes exposed on the Mark VI balloon cable 50 m. downwind. The tower was situated half way up the side of a ridge which rises a total of about 200 ft. in a distance of 1,000 yd. The vertical distributions obtained from four experiments on the same day are shown in Figure 4 where the mean number of spores per 0.11 cm. section of sampling tube is plotted against height above ground. The characteristic "cocked hat" shape of a cloud diffusing from a point source is clearly shown and the effect of atmospheric stability is demonstrated, the curves becoming narrower and the peaks greater with increasing stability. Atmospheric stability is here specified by the temperature difference between 23 and 4 ft. (23 - 4 in sign) measured on a tower approximately 2 miles away. It will also be noted that the positions of the peaks become progressively higher during the series of experiments and it will be seen later that this feature is associated with variations in the mean inclination of the wind.

Owing to movement of the "sampling balloon", there are fluctuations in the heights of the sampling tubes. The apparent spread of particles is thus a resultant of the true spread due to atmospheric diffusion and that due to the movement of the sampling tubes. No attempt has been made here to eliminate the latter component but theodolite observations showed that the standard deviation of the variation in height of the sampling tubes was approximately 0.5 m. in Experiments 3 and 4 and about 1 m. in the case of Experiment 1. These values are small in relation to the observed vertical spread of the spores. No theodolite measurements were made in the case of Experiment 2 but it seems reasonable to assume a variation of the same order.

During these experiments, readings were made at 5 second intervals of the

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inclination of the wind to the horizontal using a "V" hot wire anemometer of the type described by Simmons and Bailey (1927). This was positioned at the top of the tower a few feet away from the dispenser. The quantity measured is actually the instantaneous value of $\frac{w'}{u}$ where w' is the vertical component of velocity and u the horizontal component in the direction of the mean wind. Since the initial trajectories of the spores are determined by the local eddy velocities at the point of release their subsequent vertical distribution, when related to the elevations of the sampling positions with respect to the source, should at first approximate closely to the frequency distribution of the wind inclination. A test of this is given in Figure 5(a) for the case of Experiment 3 of Figure 4. The wind inclination was actually read to the nearest whole degree but in preparing the histogram, the observations were grouped in intervals of two degrees centred on even values, odd values being divided equally between adjacent intervals. The peak of the particle distribution curve was brought into correspondence with that of the wind distribution by suitable adjustment of scale. Bearing in mind the slight overestimation due to balloon movement the results indicate that the vertical spread of the spores for a time of travel of about 10 seconds is in close agreement with the wind inclination distribution at the point of release. A similar comparison has been made for Experiments 1, 2 and 4. In Nos. 1 and 2 a similar degree of agreement between the spread of the particles and the wind distribution is evident but in No. 4 the spread of particles appears to be wider than the corresponding wind distribution. The latter feature is rather difficult to understand and it is noteworthy at this point that of the four particle distributions No. 4 contains the greatest uncertainty as regards the peak value.

Turning now to the positions of the particle and wind distribution peaks, it is seen from Figure 5(a) that the former is 3 degrees below the latter. A similar difference (2 to 3 degrees) is also exhibited in the results of the other three experiments, though the effect is perhaps less convincing in No. 1 owing to a somewhat erratic wind distribution. Assuming a terminal velocity of the spores of 2 cm./sec., the relative displacement of the wind and particle distributions should be only about 0.25 degrees in the wind speeds of these experiments. The reasons for the much larger differences observed are not obvious and further investigation will be required. A further point of interest is that the systematic variation in peak position indicated in Figure 4 is apparently merely the result of a systematic variation in the mean inclination of the wind over a total range of about 6 degrees. It was noted during the experiments that the local wind direction changed and that the local ground slope in the direction of the mean wind was thereby increased by 2 degrees. This is insufficient to account for the total observed change in wind inclination and as yet no further explanation can be offered.

The experiments have recently been extended to greater heights with the dispenser mounted on the cable of a Mark X balloon and the sampling tubes on the cable of a Mark VI balloon as before. The maximum height attainable by the latter balloon is about 1,100 ft., so that at present the release of spores cannot be made above 1,000 ft. For measurement of the inclination of the wind, the "V" hot wire anemometer has been replaced by a vane instrument which is mounted on the cable in conjunction with the dispenser (see Figure 3). A sensitive vane responding to vertical air movement is held upwind of the cable by means of a bigger control vane, and the movements of the former vane recorded electrically on the ground. The details of this will be described elsewhere and it suffices here to note the principal feature, namely that the vane mounting is carried on a damped pendulum which automatically compensates for variations in the inclination of the balloon cable. There is in addition a variation in the height of the balloon, and hence of the vane support, which leads to a spurious component in the wind inclination record. In order that corrections may subsequently be made for this effect, the elevation of the vane support is observed at frequent intervals by a theodolite. Observations are similarly made on the central sampling tube since it may be necessary also to correct the apparent particle distribution for the vertical movement of both the source and the sampling apparatus.

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The results of the only experiment of this series which have been analysed completely so far are displayed in Figure 5(b), which contains the distributions of particles and of 15 sec. mean values of wind inclination.* This experiment was carried out over relatively level terrain in unstable conditions with the source at a height of 500 ft. and the sampling tubes 100 m. downwind. An adjustment of the scales has been made to bring the central regions of the two distributions to the same value approximately. The distributions are very wide and agree roughly in width if not in detail. Once again the position of the particle distribution appears to be below the wind inclination distribution by a few degrees.

From the theodolite observations, which were made at half-minute intervals, it appears that the maximum vertical movement of the vane support between consecutive readings was 20 ft., which is equivalent to a wind inclination of 1.5 degrees. The height difference between the central sampling position and the source position 15 seconds earlier, this being the approximate time of travel of the particles, showed extreme variations of $\pm$ 16 ft. or 3° in the scale of Figure 5(b). These figures again indicate that the spurious components due to balloon movement are small but it is evident that they might not be negligible in more critical examinations of the relation between diffusion and eddy fluctuations.

Concluding Remarks

From the early experiences described here it seems likely that the technique proposed could be of considerable value in studies of atmospheric diffusion. Further examination is undoubtedly required of the relation between the trajectory of the centre of gravity of the particles and the mode of the wind inclination. However, the first indication is that the vertical spread of particles after a short distance of travel is consistent with the frequency distribution of the vertical component of wind at the point of release, and this inspires confidence in the general reliability of the experimental techniques employed. Probably the greatest interest lies in the demonstrated feasibility of using the emitting and collecting devices at considerable heights above ground. At such heights not only is information on the diffusive properties greatly required, but it is likely that at times the turbulence there will approximate to the isotropic and steady conditions in which the predictions of statistical theories of turbulence can be tested. In the programme which is being followed here the main interest lies in the prospect of using diffusion measurements made by this technique in order effectively to specify the Lagrangian correlation coefficient and to make comparison with simultaneous measurements of the Eulerian correlation coefficient. ø

Acknowledgements

Arrangements for balloon flying were made by Flt.Lt. F.H. Radford, R.A.F. The original version of the dispenser was designed by W.C. Prewett, Physics Section, Porton. Measurements of the inclination of the wind were made by J.I.P. Jones, Meteorology Section, Porton.

/REFERENCES

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* The apparatus has a total response time of about 0.25 sec. and gives a continuous record of inclination.

ø While preparing this note the writers have had their attention drawn to a current N.A.C.A. issue (Technical Note No. 3570, by W.R. Mickelson, October 1955) which describes an experimental comparison of the Lagrangian and Eulerian correlation coefficients in wind tunnel flow. In this case the Lagrangian coefficient was characterised by measurements of the distribution of helium downstream of a point source.

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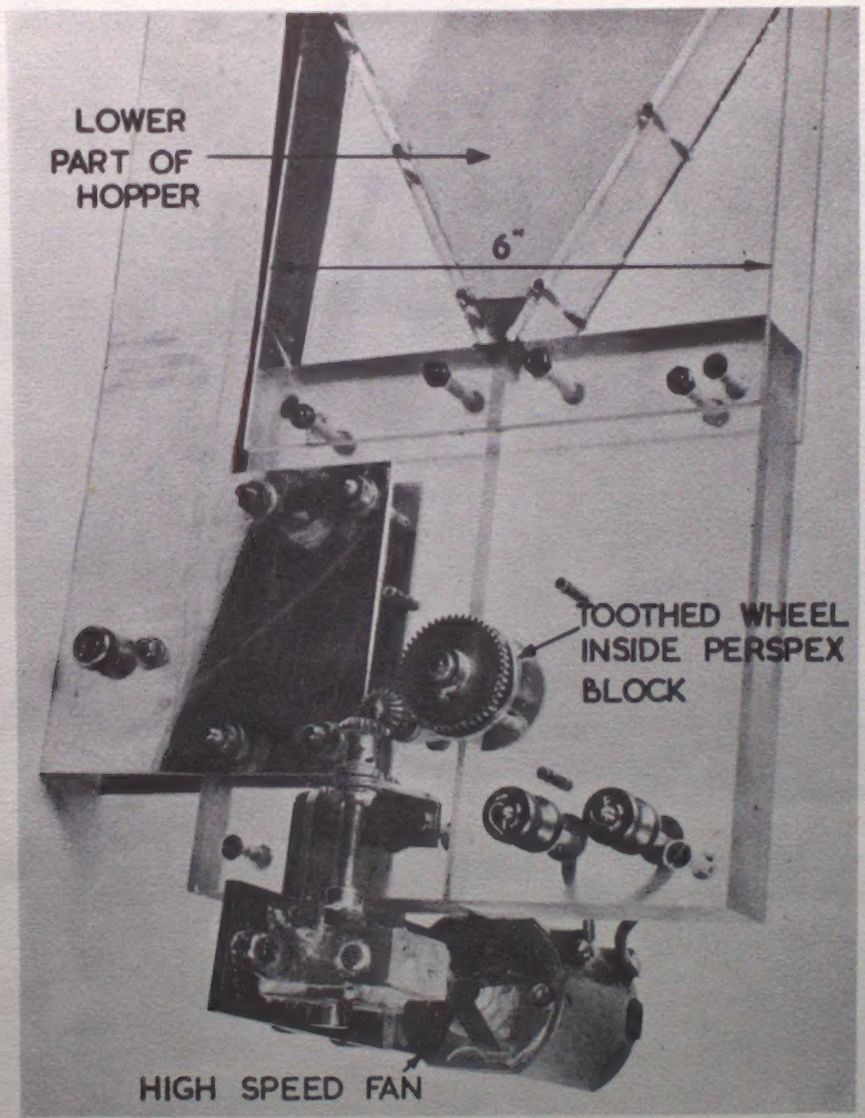
FIGURE 1. LATEST TYPE OF PARTICLE DISPENSER



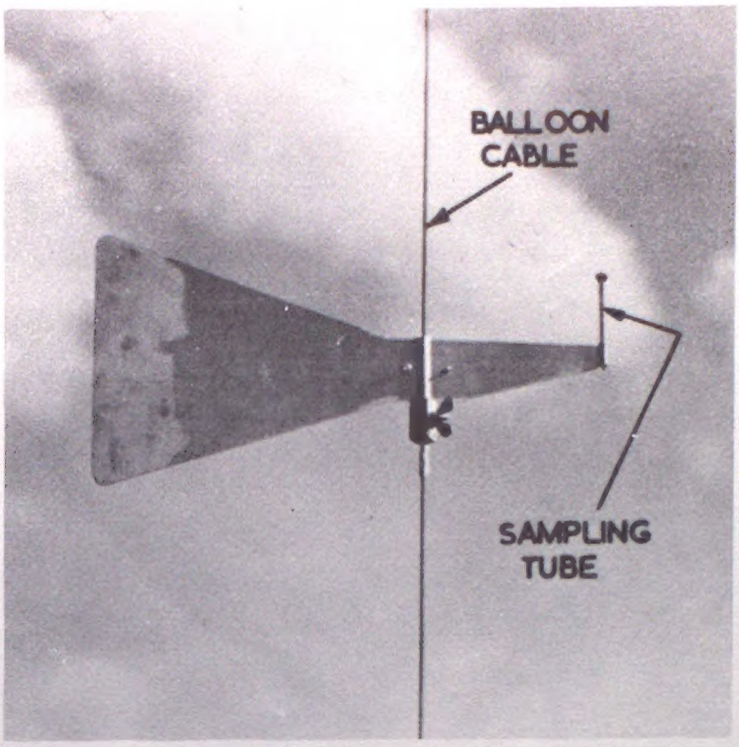


FIGURE 2. VANE CARRYING SAMPLING TUBE

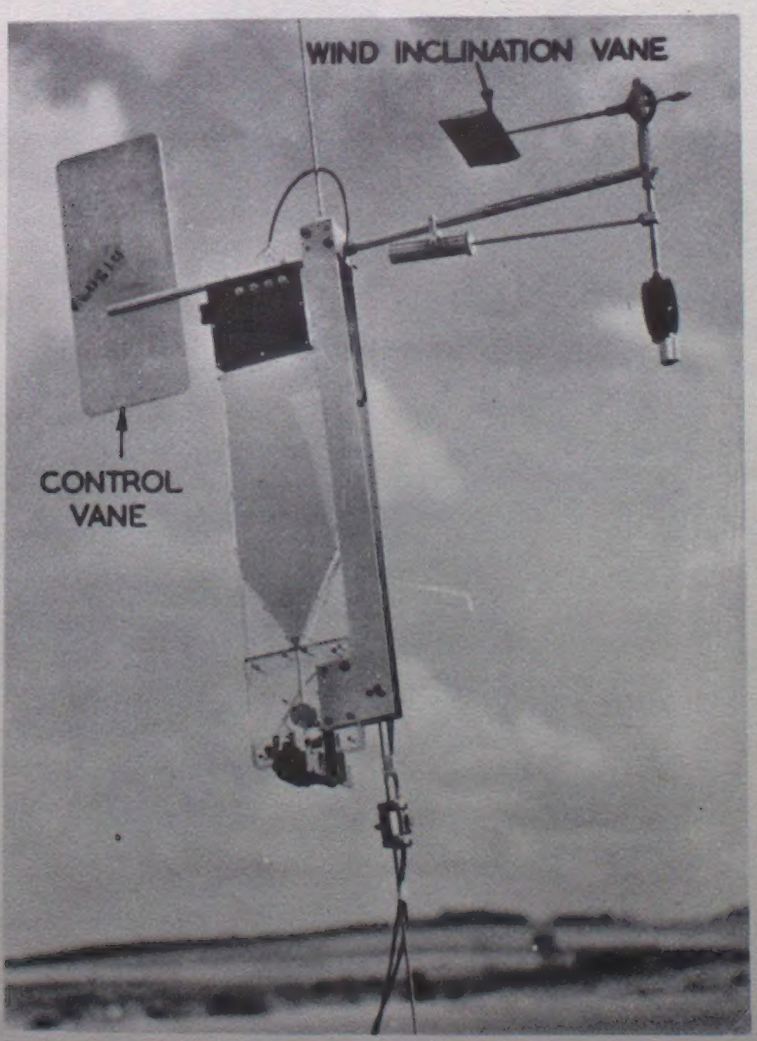


FIGURE 3. DISPENSER AND WIND INCLINATION INSTRUMENT ON BALLCON CABLE

T.1227/2.

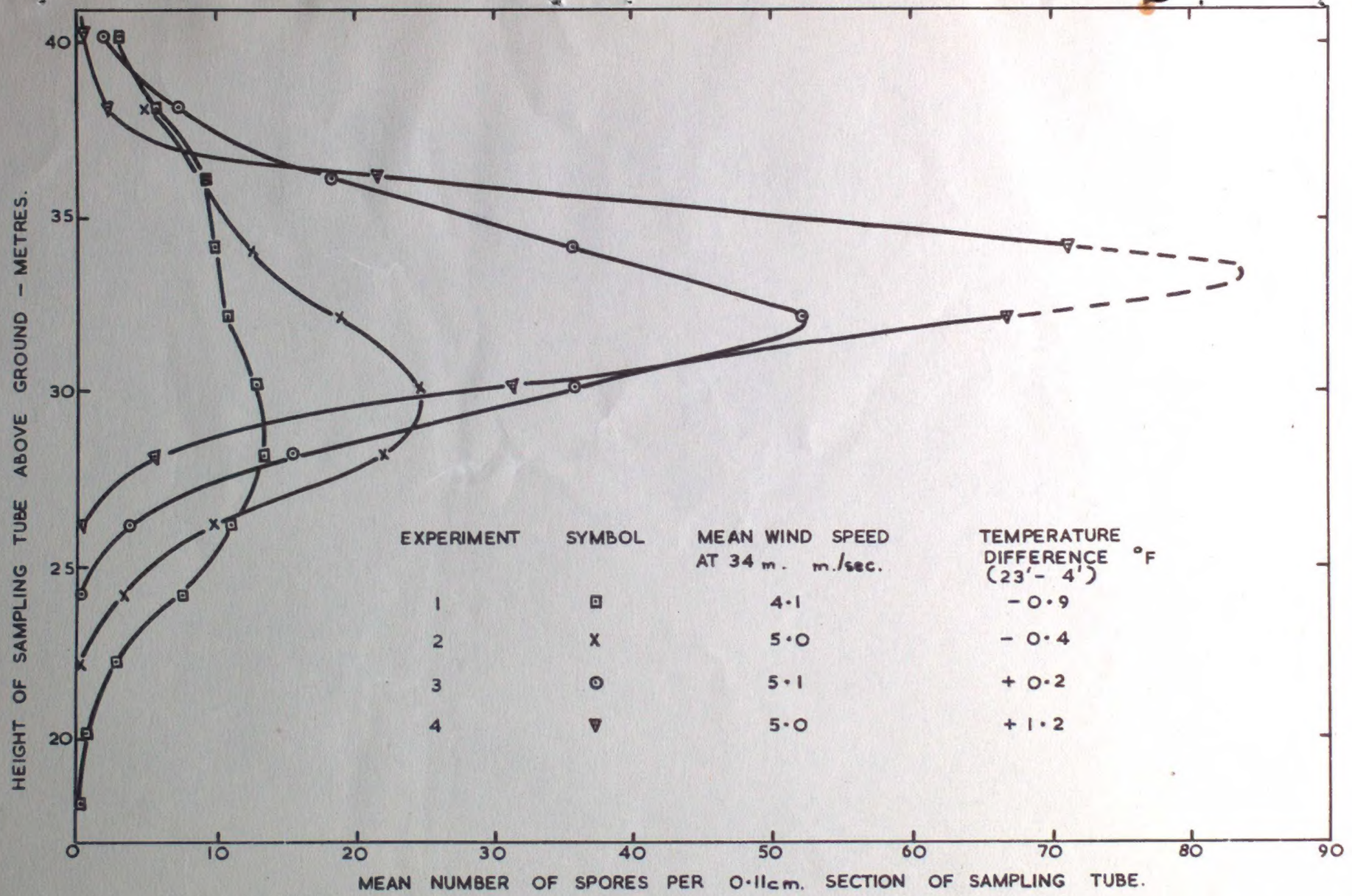


FIG. 4. VERTICAL DISTRIBUTION OF SPORES AT 50 m. DOWNWIND OF A POINT SOURCE OF DURATION 15 MINUTES AT 32·5 m. ABOVE GROUND LEVEL.

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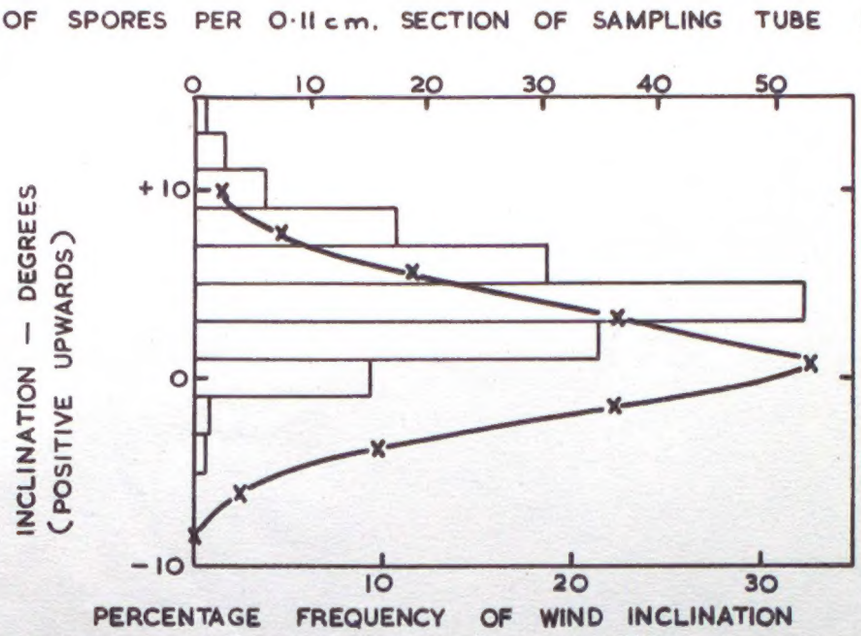
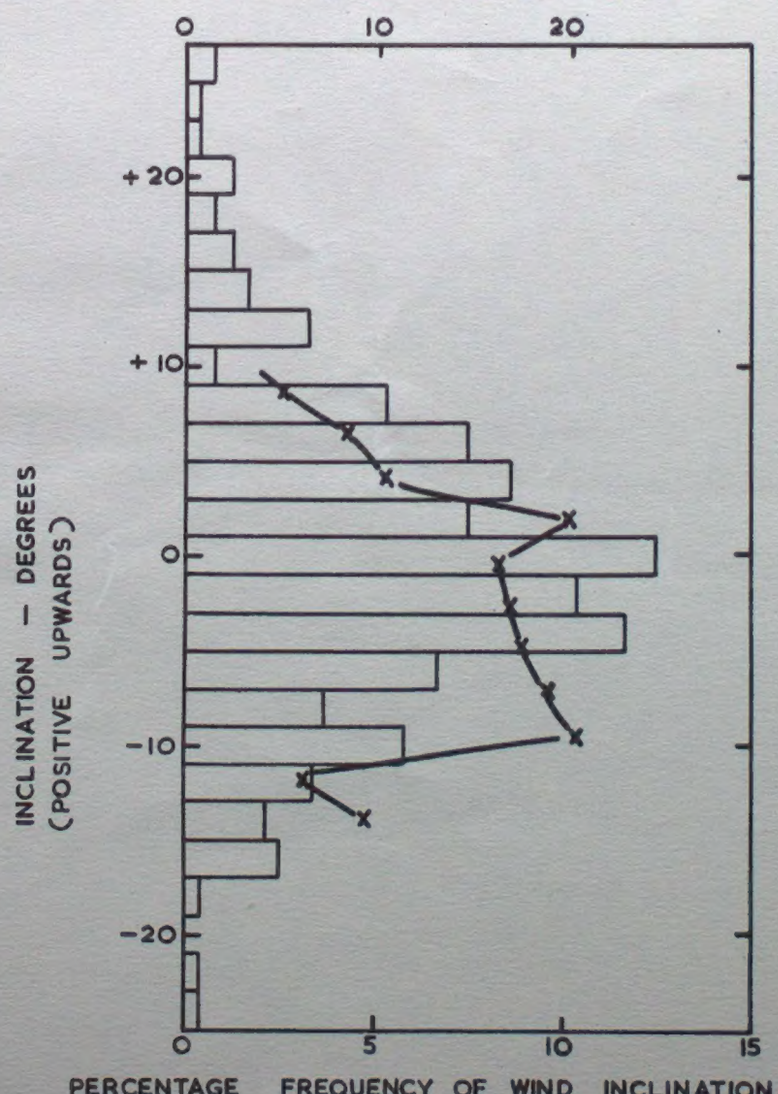


(a) SOURCE ON TOWER AT HEIGHT OF 32·5 m., SAMPLING AT 50 m. DOWNWIND, NEUTRAL CONDITIONS OF STABILITY.



(b) SOURCE ON BALLOON CABLE AT HEIGHT OF 500ft., SAMPLING AT 100 m. DOWNWIND, UNSTABLE CONDITIONS.

FIG. 5 DISTRIBUTIONS OF WIND INCLINATION AND SPORE DEPOSIT.